

to supply a current used by the oscillator circuit 100. The bias circuit 300 is connected to the current source circuit 200 to bias the current source circuit 200. The amplifier 400 is connected in a feedback loop between the bias circuit 300 and the oscillator circuit 100.

[0013] The oscillator circuit 100 comprises first and second PMOS transistors M1 and M2, respectively, connected in a negative resistance configuration across an LC tank 120. The LC tank comprises first and second inductors L and first and second PN-junction varactors C_{var} .

[0014] The PN junction varactors C_{var} are advantageous because of their high Q at the frequencies of interest (for example, in one application, the 5GHz ISM band). However, they have a parasitic substrate diode associated with the P side of the junction that has a very low Q as shown in FIG. 2. The N side of the diode is connected to AC ground to prevent the structure from having a very lossy substrate diode rendering it useless for VCO design. This is one advantage of the PMOS oscillator circuit 200 of FIG. 1. In this case, the LC tank 120 can be connected to ground rather than DC so that the diodes can be connected in the proper polarity without the need for any additional biasing.

[0015] The tank inductors L are made as large as possible to maximize the tank equivalent parallel resistance while still allowing the varactors C_{var} to be large enough so that parasitic capacitance does not reduce the available frequency tuning range to an unacceptable level. The PMOS transistors M1 and M2 themselves are sized so that they have a DC V_{GS} voltage of approximately two volts. This leaves one volt of headroom to accommodate the current source transistor 210. The inductor L_{Tail} and the capacitor C_{Tail} form a filter that is designed to filter out noise from the bias circuit 300 so that it does not affect the phase noise of the VCO 10.

[0016] The current source circuit 200 comprises first and second PMOS transistors M3 and M4 coupled to transistors M1 and M2 in the oscillator circuit 100 via inductor L and capacitor C_{Tail} . Capacitor C_1 is included to form a dominant and controllable pole in the feedback loop so that stability of the feedback loop is assured for all operating conditions.

[0017] The bias circuit 300 comprises first and second transistors Q3 and Q4 and their associated base transistors R_{B1} and R_{B2} , diode D1 and current source I_{bg} . The diode D1 provides a level shift so that the transistors Q1 and Q2 in the amplifier 400, to be described hereinafter, are not in saturation. Resistors R_{B1} and R_{B2} are included to degenerate the current mirror formed by transistors Q3 and Q4 and act to reduce the noise it generates. The current source I_{bg} is a reference current generated by a band-gap circuit on the chip (not shown).

[0018] The amplifier 400 in the feedback loop comprises first and second transistors Q1 and Q2 coupled between the bias circuit 300 and the oscillator circuit 100. The transistors Q1 and Q2 are set nominally in cut off and behave as class C amplifiers. There are emitter resistors R_E in the emitters of the transistors Q1 and Q2. The values of the emitter resistors R_E set the amplitude control behavior of the amplifier 400 as described hereinafter. The base of transistor Q1 is coupled to the gate of transistor M2 and the base of transistor Q2 is coupled to a node between a varactor and an inductor in the LC tank circuit 120. By these connections, the amplifier 400 can sense the amplitude of the voltage of the oscillator circuit 100. The transistors Q1 and Q2 are connected in such a manner so that they do not load the tank and provide additional loss when they turn on, impacting phase noise. This is an important advantage over previous designs that load the tank with the dynamic emitter resistance of the limiting transistors. Thus, in this design, the transistors Q1 and Q2 do not act as clamping diodes.

[0019] Generally, it is difficult to set the current in the VCO 10 to an optimal level with any accuracy. The current required by the VCO 10 to achieve a given output level will change over the frequency tuning range (with changes in varactor C_{var} and inductor L) over temperature and process. The feedback mechanism, an example of which is described above, sets the current in a very accurate manner.

[0020] In operation, the transistors Q1 and Q2 in the amplifier 400 have no effect on the oscillator circuit until the oscillator voltage amplitude reaches a desired level (set by values for the emitter resistors R_E) corresponding to the positive peak of the oscillation voltage. Once this level is reached, transistors Q1 and Q2 turn on briefly and steal/draw current away from transistor Q4 in the bias circuit 300. This in turn

[0022] FIG. 3 shows simulation results for a VCO using the design of FIG. 1, where current through the oscillator (in transistor M3) settles to its final value of about 7.5mA after an initial transient. The final current of the oscillator circuit 100 in this simulation example runs between 7.5mA and 8.8mA depending on the bias on the varactors, which runs between 0.3V and 2.45V (about 300mV from the supply rail). The voltage in the LC tank settles to a constant 4.5Vpp independent of frequency as shown in FIG. 4. The phase noise for this design has also been simulated and found to vary by no more than a few tenths of a dB over the entire tuning range, as shown in FIG. 5 (108.4dBc/Hz at 100kHz offset from a 4.9GHz carrier).

[0023] In sum, a voltage controlled oscillator is provided comprising an oscillator circuit having an LC tank circuit and first and second transistors connected in a negative resistance configuration across the LC tank circuit. The oscillator circuit generates an oscillator voltage proportional in frequency to an input control voltage and proportional in amplitude to an input control current. A current source circuit is coupled to the oscillator circuit that supplies the input current to the oscillator circuit. A bias circuit is coupled to the current source circuit that biases the current source circuit. A feedback loop is coupled between the bias circuit and the oscillator circuit, wherein the feedback loop comprises an amplifier having a high input impedance that is coupled to sense the oscillator voltage and output a current proportional to a

positive peak of the oscillator voltage to reduce current flowing into the oscillator circuit from the bias circuit by enough to control the level of swing of the oscillator voltage to a desired level.

[0024] The above description is intended by way of example only.